Analysis of ARGOS Data, Algorithm Development and Spectroscopic Modeling for Space Weather Applications

Ronald J. Thomas
Electrical Engineering Department
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801
phone: (505) 835-5683 fax: (505) 835-5332 e-mail: thomas@nmt.edu

Ken Minschwaner
Physics Department
New Mexico Institute of Mining and Technology
Socorro, New Mexico 87801
phone: (505) 835-5683 fax: (505) 835-5707 e-mail: krm@kestrel.nmt.edu

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LONG TERM GOALS

The focus of our research is the global remote sensing of the ionosphere via ultraviolet emissions observed from space. We are developing optimal methods for inverting satellite-based measurements using nonlinear techniques. One aspect of this work involves understanding the effects of latitude gradients and including these in the inversion algorithm. Another primary concern is development of rigorous error estimation techniques.

A second aspect of this project involves high-resolution synthesis and modeling of UV emissions based on recent laboratory measurements.

SCIENTIFIC OBJECTIVES

The scientific objectives are to develop a 2-D model, inversion codes and other computer tools needed to understand and use UV observations from space. These tools should be tested on real spacecraft observations. The second objective is to generate high-resolution synthetic spectra of O^2 for analysis of future observations.

APPROACH

We have and continue to develop, improve, and test accurate fast forward model sections. The forward model sections are then integrated into inversion drivers for the satellite UV observations. Methods that use the 1-D inversion results to create the 2-D inversion results are being tested and changed. A new 1-D inversion is being developed that does not constrain the result to any model such as the chapman layer.

Use data from the GLO experiment flown on the shuttle to find both ionosphere and neutral densities as a test of a multiple emissions inversion. This success shows that airglow observations from a spacecraft can be used for space weather applications.

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For the second primary objective, we are constructing line-by-line codes for the synthesis of molecular oxygen UV Herzberg spectra in the lower ionosphere.

WORK COMPLETED

We have developed and verified fast and accurate programs to compute line of sight optical depths and intensities as observed by a spacecraft, including latitudinal variations. The first inversion algorithms for limb measurements that we developed in conjunction with NRL assumed a uniformly stratified atmosphere. The effects of latitude gradients were ignored. For many situations this is a good assumption, however often it will cause errors. We investigated the effect of latitude variations on inversions and found ionospheric errors in areas of steep gradients. We developed a 2D inversion and found improvements in the results.

The GLO data obtained from the Space Shuttle has been analyzed. Jin Wu has completed his thesis research, passed his oral exam, should have his dissertation accepted very soon. We used 12 dayglow emissions to infer the densities of O, N2, O2, temperature, and electron density in the thermosphere. The densities of metastable species related to the airglow were inferred. He also used the analysis to improve two reaction rates by solving for these as part of the inversion. We have submitted a paper, Wu (1998).

We have established a relationship with Brian Borchers, a faculty in the math department and masters student Jon Stinger. Jon has made initial tests to developing a method to invert the 834 emission to ionosphere density that is not constrained to the chapman function. He is using Tikhonov regularization to find a smoothly varying solution specified by the densities at about 10 altitudes.

A line-by-line synthesis of the oxygen Herzberg I bands has been validated through comparison with FTS absorption measurements from the Harvard-Smithsonian Center for Astrophysics (CFA) [Yoshino et al., 1994], using A-state terms values, oscillator strengths, and relative branch strengths based on the high resolution CFA measurements. The Herzberg I spectral model contains 10 branches spanning vibrational levels v'=4-11 and v"=0-5, and rotational levels up to N"=23. The computations have a spectral grid of 0.05 cm-3 (the Doppler width at 295 K is approximately 0.09 cm-1).

For Herzberg I emission spectra, we adopt band strengths from the measurements by Hasson et al. [1970]. The assumed vibrational distribution of the A state is taken from the model results of Siskind and Sharp [1990] for intermediate quenching, which is based on the rocket measurements from Sharp and Siskind [1989]. This distribution can alternatively be retrieved from future measurements.

RESULTS

Observations of 834 A intensities were simulated for an entire orbit. These observations were inverted in several ways. Figure 2 shows the results of these test inversions. The errors resulting from the 1-D and from the 2-D inversions are also shown. The error in the 2-D inversion is smaller.

The analysis of the GLO data has demonstrated that the upper atmospheric and ionospheric densities can be inferred from the measurement of multiple airglow emission profiles. Typical results are shown in Figure 1.

Comparisons of our Herzberg I synthetic spectra with rocket measurements of the oxygen nightglow [e.g., Siskind and Sharp, 1990] indicate discrepancies which appear to be related to the Herzberg II and III systems. Contributions to the oxygen emission spectrum from the Herzberg II system, first identified by Slanger and Huestis [1981], are absent from the synthetic spectrum but do appear in the nightglow, particularly since the Herzberg II band heads are well separated from those of the Herzberg I. Additionally, Sharp and Siskind [1989] identified the Herzberg III 6-2 band near 2815 A in their rocket measurements.

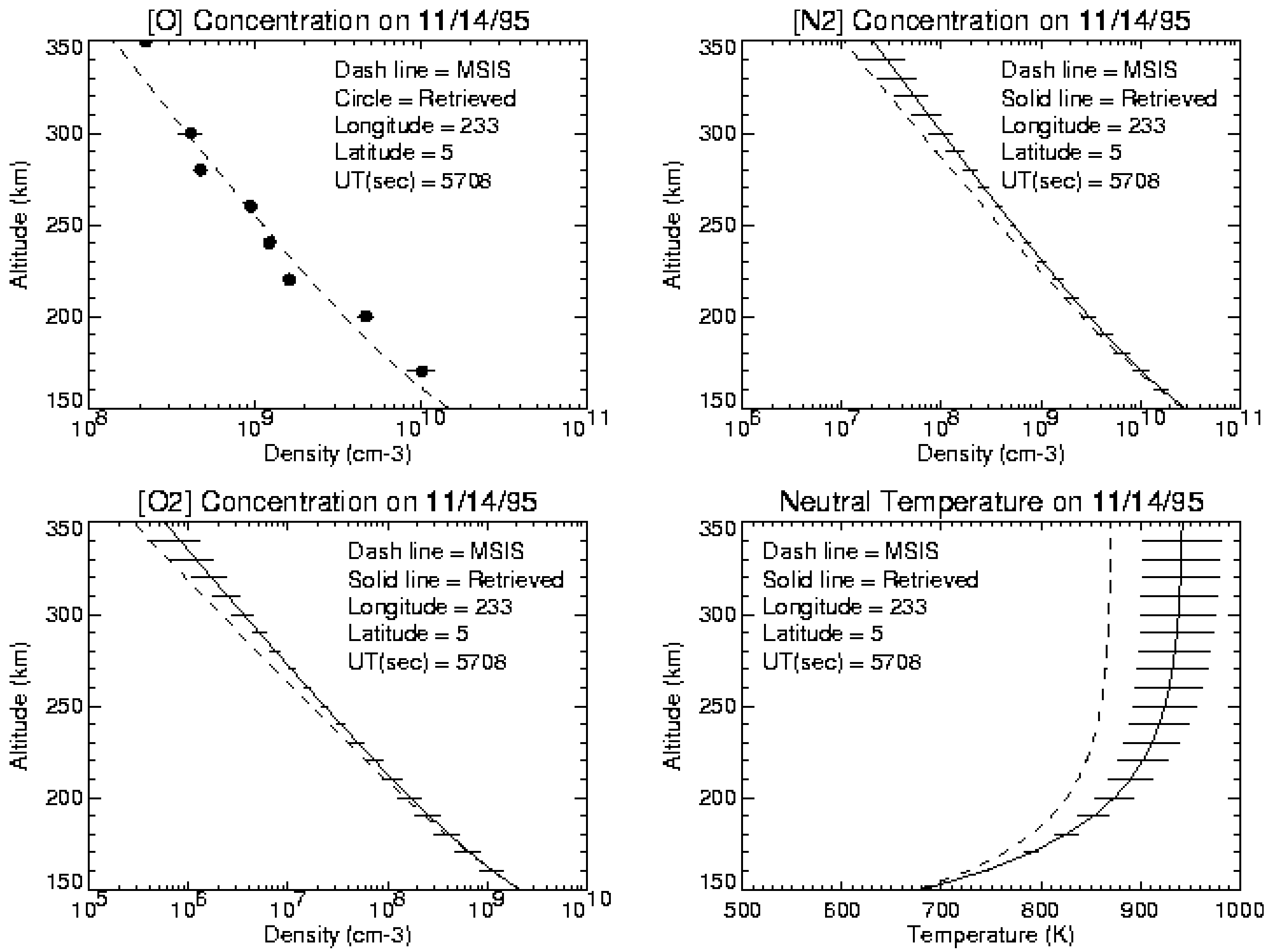

Figure 1.Rerieved atomic and molecular oxygen, nitrogen, and temperature profiles. These profiles were retrieved simultaneously from the GLO 12 dayglow line observations.

We have included Herzberg II emission into the spectral model using a line-by-line analysis similar to that used for the Herzberg I system. The Herzberg II synthesis includes the R and P branches over the vibrational levels v'=1-12 and v"=0-5, and rotational levels up to N"=25. Term values for the c state are based on the absorption measurements by Ramsay [1985], and transition probabilities are from Bates [1989]. A preliminary estimate of the c-state vibrational distribution is taken from Slanger and Huestis [1981]. The shape is similar to the A-state vibrational distribution but the peak is shifted by about 3 quanta to higher vibrational levels. Here again, it may be possible to infer c-state vibrational distributions from future measurements.

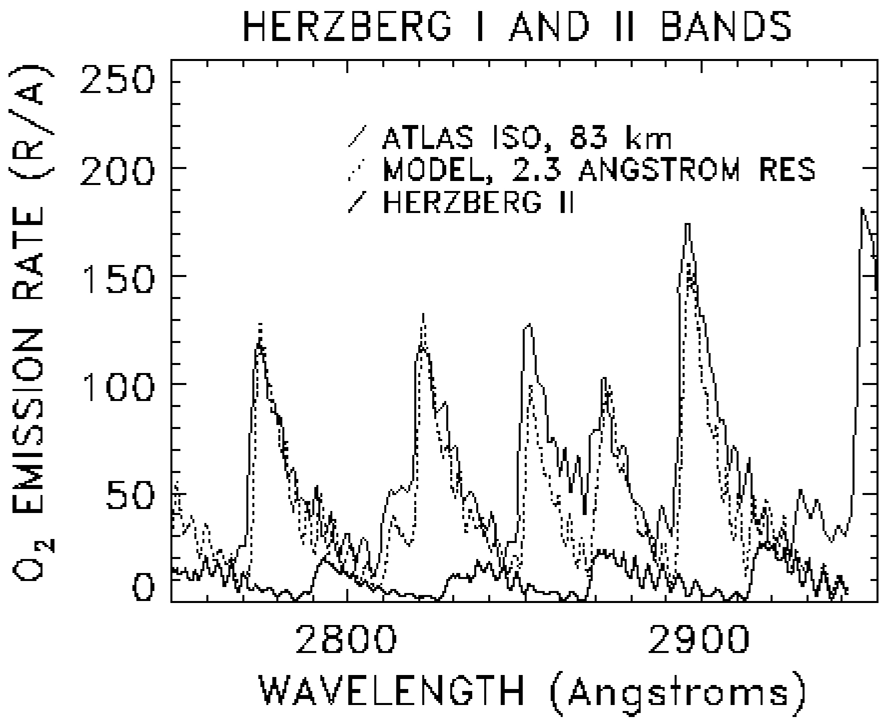

Figure 2. Oxygen band emission near 83 km tangent altitude observed with he ISO instrument, synthetic spectra, and newly added Herzberg II system.

The improved comparison to ATLAS ISO measurements [Torr et al., 1995] is shown in Figure 2. The measurements were obtained with a high-resolution imaging spectrograph deployed from the space shuttle to observe the night limb. Also shown is the contribution from the Herzberg II system, as well as the spectral model resulting from the sum of the Herzberg I and II emissions. At about 2 A spectral resolution, the rotational structure within bands of the Herzberg I system is observable. The intensity of the Herzberg II bands is not sufficiently high to permit identification of rotational structure in the composite spectrum; however, the Herzberg II bands are clearly shown to contribute to the total emission, particularly the (10,2) and (7,2) bands near 2790 and 2913 A, respectively. Further improvements might be expected with the inclusion of Herzberg III bands. Sharp and Siskind [1989] identified the Herzberg III 6-2 band near 2815 A in their rocket measurements; inclusion of this band in the model might improve the agreement in this spectral region.

IMPACT/APPLICATIONS

Improved techniques for ionosphere monitoring will lead to better models and predictions of electron and neutral densities.

The upper atmospheric and ionospheric densities can be inferred from the measurement of multiple airglow emission profiles.

The goal of the spectral work is to extract information from future satellite measurements obtained at higher spectral resolution (~1 A). Oxygen A-state densities, vibrational distribution, and inferred quenching rates should be relatively straightforward to obtain. We also will examine the retrieval of rotational temperatures from Herzberg I band structure at this spectral resolution. As indicated in Figure 2, identification of the Herzberg II (and possibly Herzberg III) bands is feasible from satellite data. Using the expanded spectral model, densities of c-state (and A'-state) oxygen may be constrained from future observations.

TRANSITIONS

RELATED PROJECTS

The inversion algorithms will be used to help interpret the measurements of the ARGOS spacecraft. We have developed inversion algorithms in conjunction with NRL for a uniformly stratified atmosphere. Inversions the include the effects of latitude variation can also be used to find densities that effect the drag predictions of Robert Tolson. The inferred ionospheric densities will be comparison to the ionospheric models of Ray Roble.

We have the capability to accurately model spectral signatures in the O_2 Schumann-Runge and NO delta bands (e.g., Minschwaner and Siskind, 1993) which can be observed, for example, with the 1 A MUV spectrograph being developed by Bill McClintock at the University of Colorado. Additional progress, as noted above, is being made on the spectra of the oxygen Herzberg I and II bands.

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